DOCUMENT RESUME

ED 182 573 CE 024 258

AUTHOR Espy, John: Selleck, Ben
TITLE Nuclear Technology. Course 27: Metrology. Module 27-6, Calibration.
INSTITUTION General Physics Corp., Columbia, Md.
SPONS AGENCY Office of Education (DHEW), Washington, D.C.
PUB DATE 79
CONTRACT 300-77-0340
NOTE 48p.: For related documents see CE 024 245-298

EDRS PRICE MF01/PC02 Plus Postage.
DESCRIPTORS Course Content: Energy: Learning Activities: Learning Modules: *Measurement: *Measurement Instruments: Measurement Techniques: *Nuclear Physics: Postsecondary Education: *Quality Control: Teaching Guides: *Technical Education
IDENTIFIERS Calibration: Nuclear Energy: Nuclear Energy Occupations: *Nuclear Power Plant Technicians: *Nuclear Technology

ABSTRACT

This sixth in a series of eight modules for a course titled Metrology describes the principles on which calibration programs are developed, no matter which instruments are included in the calibration program. The module follows a typical format that includes the following sections: (1) introduction, (2) module prerequisites, (3) objectives, (4) notes to instructor/student, (5) subject matter, (6) materials needed, (7) procedures, (8) data table, (9) reference materials, (10) test. (The course is one of fifteen technical courses for the second year of a two-year postsecondary curriculum in Nuclear Quality Assurance/Quality Control Technology.) (LRA)

****
* Reproductions supplied by EDRS are the best that can be made *
* from the original document. *
****

ED182573

NUCLEAR TECHNOLOGY

COURSE 27 METROLOGY

MODULE 27-6 Calibration

U S DEPARTMENT OF HEALTH, EDUCATION & WELFARE
NATIONAL INSTITUTE OF EDUCATION

THIS DOCUMENT HAS BEEN REPRODUCED EXACTLY AS RECEIVED FROM THE PERSON OR ORGANIZATION ORIGINATING IT. POINTS OF VIEW OR OPINIONS STATED DO NOT NECESSARILY REPRESENT OFFICIAL NATIONAL INSTITUTE OF EDUCATION POSITION OR POLICY

CE 024 258

GENERAL PHYSICS CORPORATION
Columbia , Maryland

COURSE MODULES

COURSE 27 METROLOGY

Module 27-1	Fundamentals of Metrology
Module 27-2	Fixed Gages, Dividers, Calipers and Micrometers
Module 27-3	Gage Blocks, Mechanical Comparators and Electronic Comparators
Module 27-4	Angle Measurement Instruments, Optical Projectors and Surface Texture Gages
Module 27-5	Tolerancing
Module 27-6	Calibration
Module 27-7	Statistical Techniques in Metrology
Module 27-8	The Total Measurement System

The material in this module was developed by General Physics Corporation under a contract with the United States Department of Health, Education and Welfare, Office of Education, Contract Number 300770340. Contractors undertaking such projects are encouraged to express freely their professional judgment in the conduct of the project. Therefore, points of view or opinions stated do not necessarily represent official Office of Education position or policy.

This module was prepared for General Physics Corporation by John Espy, General Physics Corporation, and Ben Selleck, Ben-Sel Associates.

GENERAL PHYSICS CORPORATION

1979

INTRODUCTION

Prior modules of this course have described a number of measuring instruments and their applications. Such measuring instruments are not suitable for inspection of product unless they are calibrated. Through the process of calibration, the accuracy of each measuring instrument is maintained within established limits thusly making the instruments suitable for inspection functions.

One can view the role of calibration from the buyer's viewpoint or the seller's viewpoint. From the buyer's point of view, the major role of calibration is to ensure acceptance inspection measuring devices are sufficiently accurate. This outlook is focused toward ensuring final product conforms with specified requirements. From the seller's viewpoint, it is equally important to ensure that each manufacturing step has sufficient accuracy to produce a product which will conform to specified requirements. Since nonconforming product always means extra costs, the buyer's and seller's views tend to agree on the need for accurate in-process measuring instruments to avoid extra costs. In most cases, government regulations approach calibration from the buyer's viewpoint.

If only the buyer's parochial view toward acceptance inspection is considered, the calibration program would include only those measuring devices used to determine if final product conforms with specified requirements. The seller's point of view adds to the calibration program those measuring devices used to establish the accuracy of discrete manufacturing steps. Therefore, many organizations include all measuring devices in their calibration program whether the instruments are used by manufacturing personnel or QA/QC inspectors.

This module describes the principles on which calibration programs are developed no matter which instruments are

included in the calibration program. The module then describes the key elements of a calibration program based on these principles. Finally, exercises are suggested for students/trainees to prepare calibration procedures and perform calibrations of selected instruments. Both of these functions may be performed or reviewed by the QA/QC Technician.

MODULE PREREQUISITES

The student/trainee shall have completed all previous modules of this course.

OBJECTIVES

Upon completion of this module, the student/trainee shall be able to do the following:

1. Define the terms calibration, traceability, national standard, reference standard, and out-of-calibration.
2. Describe the role of the U.S. National Bureau of Standards with respect to calibration.
3. State the principle and describe its role in the calibration program associated with each of the following:
   a. Tolerance-to-Accuracy Ratio
   b. Traceability
   c. Accuracy of Calibration
   d. Interval of Calibration

4. Given any of the ten elements of a calibration program, briefly describe its contribution to the calibration program.
5. Name four sources which may independently cause an instrument to be out-of-calibration.
6. Name any two methods of adjusting calibration intervals and briefly describe the key features of each.
7. Given a type of record used in the calibration program, state the purpose of the record and describe its use.
8. Demonstrate the ability to verify the adequacy of calibrations by either performing calibrations or evaluating calibrations performed by others.

NOTES TO INSTRUCTOR / STUDENT

Laboratory exercises are recommended to develop student/trainee skills in development of written procedures describing a calibration program and in performing basic calibration. This module includes suggested exercises of this purpose although the instructor will need to tailor these to local circumstances. Advance preparation will be necessary for:

1. Determining if a tour of a commercial calibration laboratory will be included.
2. Selection of instruments to be calibrated.
3. Selection of standards and measuring instruments to be used in the calibration procedure.

TERMINOLOGY

Many of the terms used throughout industry and government with respect to standards and calibration lack universally accepted definitions. This is particularly evident with descriptive terms for standards such as "qualified", "basic", "fundamental", and "absolute". Therefore, the QA/QC Technician must be alert for the meaning of terms as intended by the author of literature on calibration.

- Calibration - The comparison of an instrument with a reference standard or with an instrument of equal or closer tolerance to detect and quantify inaccuracies and to report or eliminate those inaccuracies.
- Traceability - The ability to trace the calibration of an instrument and/or standard to the national standard or to accepted physical constants.
- National Standard - The embodiment of the unit of measurement either physically or by procedural technique as maintained by the U.S. National Bureau of Standards.
- Adjustment - The manipulation of adjustable features of an instrument to bring the instrument's accuracy and/or precision closer to the corresponding values of the standard.
- Repair - The replacement of parts of an instrument to bring the instrument's accuracy and/or precision closer to the corresponding values of the standard.
- Reference Standards - The primary, secondary and working standards which are used in a calibration program and which establish the basic accuracy limits for that program.

- Uncalibrated Instrument - An instrument or standard that is not subject to the calibration program. (This term is used by some to mean an instrument past due for calibration and by others to mean an instrument which is out of calibration. See Calibration Not Required.)
- Out of Calibration - An instrument or standard found at calibration to have accuracy outside the specified accuracy limit. (This term is used by some to mean an instrument which is overdue for calibration).
- Overdue or Delinquent Instrument - An instrument or standard subject to the caibration program but is presently overdue for recalibration. (NOTE: a deliquent instrument is not necessarily out of calibration; its accuracy is considered unknown until it is recalibrated.)
- Calibration Not Required - An instrument or standard which is not required to be calibrated. (Basis must be documented.)

ROLE OF U.S. NATIONAL BUREAU OF STANDARDS

Module 27-1 describes units of measurement and the role of the U.S. National Bureau of Standards with respect to maintaining either test procedures or physical specimens which embody the unit of measurement. Such test procedures or physical specimens serve as the national standard to which all calibrated measuring instruments in the United States are traceable. The final step in traceability is achieved by the calibration services offered by the U.S. National Bureau of Standards. These calibration services are offered at a fee and are limited to the highest order

of reference standards used by industry and other government agencies. (See Hierarchy of Standards, Module 27-1.)

PRINCIPLES OF OPERATION

The inspection process involves a triad of disciplines. First, the designer stipulates on drawings the sizes, forms and positions to be met by the manufacturing processes. Secondly, the inspection activity determines the acceptance of the manufactured items to the designer's requirements through the use of calibrated measuring instruments. Thirdly, the calibration of measuring instruments is traceable to a national standard. Regardless of which organization designed, manufactured, or inspected the product and regardless of which organization calibrated the measuring instruments and reference standards uniformity of results is necessary to ensure fit, function and interchangeability of product. Such uniformity is possible by the application of principles associated with tolerance-to-accuracy ratio, traceability, accuracy of calibration, and intervals of calibration.

Tolerance-to-Accuracy Ratio

The capability of an instrument and its accuracy determine if it is suitable for use in a given measurement or calibration process. The tolerance of the feature to be measured can dictate the type of instrument to be selected and demand certain accuracy of the instrument. For example, a tolerance of $\pm$.005 inch demands more accuracy than a tolerance of $\pm$.050 inch. If the accuracy of instruments are known, selection of an instrument for use is based on the tolerance of the feature to be measured. The principle of selecting an instrument that gives a 4 to 1 (or 10 to 1) tolerance-to-accuracy ratio ensures use of a sufficiently accurate instrument.

Traceability

The demands of competitive industry and, in some cases, federal or state laws require traceability of measuring instruments. The principle of every measuring instrument and standard having traceability regardless of the number of intermediate calibration steps ensures that the accuracy of every instrument or standard is ultimately based upon the same value, i.e., the national standard or accepted physical constants. Such traceability involving a commerical calibration laboratory is illustrated in Figure 27-6-1. If any link in the calibration chain is broken, the ultimate accuracy embodied in the national standard is not reflected in the measurement of the part; hence, the need for traceability.

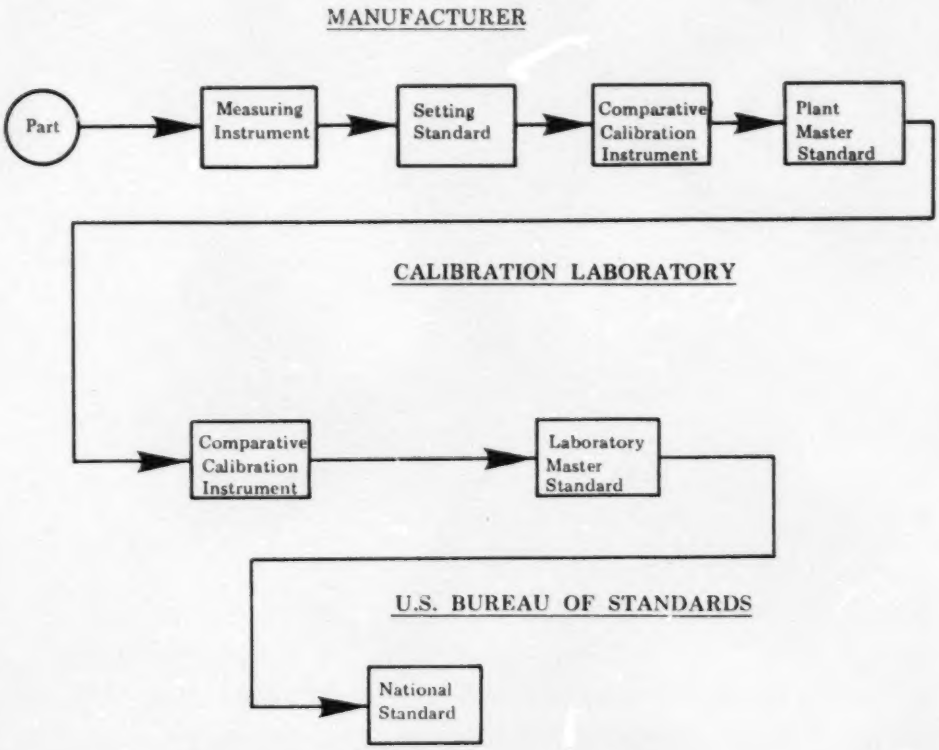

Figure 27-6-1 Traceability

Accuracy of Calibration

Controversy quickly erupts whenever discussions arise on "required" accuracy of calibration. This is because few types of instruments have calibration accuracies defined by national standards. Also, there is not agreement on the need to establish national standards for calibration of many instruments.

Calibration accuracy limits are established for certain measuring instruments and standards. For example, ANSI B 89.1 establishes accuracies of the various grades of gage blocks. ANSI B1.2 establishes accuracies of gaging for the inspection of unified screw threads. However, these standards do not give requirements for the calibration of the instrument used to test the accuracy of the gage block or the thread gages.

Gages having many applications are not generally subject to a national standard. Examples of such gages are micrometers, vernier calipers, dial indicators, test indicators, electronic comparators, optical projectors, and engineering microscopes. Nonetheless, literature on the "recommended" accuracies of calibration of these instruments is published by several sources including U.S. National Bureau of Standards, manufacturers of such instruments, research institutions, and individual's articles in technical periodicals.

Chaos does not (or should not) result from a lack of national standards on calibration accuracies. This is because the capability and intended use of the item to be calibrated dictates the calibration accuracy. Each company establishes calibration accuracies for each type of measuring equipment and defines these accuracies in the calibration procedures. The principle for calibration accuracy of dimensional inspection instruments is that each instrument

is corrected at calibration to be accurate to a defined value. This establishes the accuracy of quality level for measurements and tests. Application of this principle for the instruments listed in Figure 27-6-1 is illustrated in Table 27-6-1. Practical limits are imposed by "state-of-the-art" calibration techniques.

The correction of an instrument's accuracy at calibration may be accomplished by adjustment, repair, or correction curves. Instruments which do not lend themselves to adjustment or repair can still be used if correction curves are developed. These curves plot known error against range. The error value of the size being measures is used to correct the measurement result.

Table 27-6-1

Calibration Accuracy for Part Tolerance of 0.010

Instruments Listed in Figure 27-6-1	Calibration Accuracy	
	Ten-to-One Rule	Four-to-One Rule
Measuring Instrument	0.001	0.0025
Setting Standard	0.0001	0.000625
Calibration Instrument	0.00001	0.000156
Plant Master Standard	0.000001	0.000039
Laboratory Calibration Instrument	0.000001*	0.0000098
Laboratory Master Standard	0.000001*	0.0000024
National Standard	0.000001*	0.000001*

*Practical state-of-the-art limit for dimensional measurement is ± 0.000001 inch.

12

Intervals of Calibration

Once an instrument is calibrated, it tends to lose accuracy with time and use. Calibration is repeated at periodic intervals to maintain the accuracy of the instrument. Methods of determining such time intervals are described later in this module. The principle is stated as intervals of calibration are selected such that a high probability exists that instruments are recalibrated prior to the accuracy of the instrument exceeding its designated limit. The probability value is dependent on a company's policy. This principle provides for assurance within the probability value that instruments are accurate to defined limits at any time of their use.

ELEMENTS OF THE CALIBRATION PROGRAM

Each organization is faced with establishing a calibration program for the measuring devices on hand and for each new instrument when purchased. Whether the organization provides its own calibration laboratory or contracts for services by a commercial calibration laboratory, a documented calibration program is established to ensure that suitability accurate instruments are made available to inspection and test activities. Elements of the documented program are summarized as follows and more fully described in subsequent pages:

- Equipment Identification - Each measuring and test instrument and reference standard is uniquely identified by a serial number and assigned location.
- Calibration Procedures - Written procedures provide instruction on techniques used for calibrating each instrument.

- Intervals of Calibration - Specific time intervals are established for the recalibration of instruments.
- Recall Procedures - Positive means are established for recalling instruments which are due for calibration.
- Traceability - The methods of demonstrating traceability are established.
- Precalibration Checks - Accuracy of used equipment is checked prior to adjustment or maintenance.
- Labeling - The calibration status of instruments is clearly identified.
- Nonconformance - Practices are established for the identification and correction of nonconformances.
- Environmental Controls - Necessary environmental controls are established.
- Records - The specific records to be maintained are defined.

Equipment Identification

Each measuring device and standard is serialized to permit traceability of each. The serialization must avoid assignment of duplicate serial numbers such that any instrument is identifiable by its unique number.

Serialization schemes vary from company to company. Some use alpha-numeric serialization and other use only numeric serialization. Some incorporate manufacturer's serial numbers and assign local serial numbers only to those gages which are not serialized by the manufacturer. As long as each instrument has its own unique serial number, the scheme selected should work. However, as the number of instruments and standards increases, as well planned serialization scheme becomes increasingly important. Where thousands of instruments and standards are to be controlled,

a nine-digit serialization scheme finds widespread use. It has the advantage of encompassing up to 999 identical instruments and completely identifying each instrument solely by the serial number. Such a scheme is illustrated in Figure 27-6-2.

	Type of Instrument	Range or Number of Pieces in the set	Consecutive Number
Serial Number:	XXX	XXX	XXX

Example where 265 is assigned for outside micrometers.

265 001 412 means:

265 identifies the instrument as an outside micrometer

001 identifies an 0-1 inch range

412 identifies it as the 412th. outside micrometer of this range

Example where 085 is assigned to gage block sets.

085 035 002 means:

085 identifies the instrument as a gage block set

035 identifies it as a 35 piece set

002 identifies it as the 2nd. such set

Figure 27-6-2 Nine Digit Serialization Scheme

Assignment of the first three digits of the nine digit serialization scheme is normally accomplished from an alphabetical listing of each type of instrument. Once the alphabetical listing is made, a three digit number is assigned for each type. Where there is possibility of purchasing additional types or of exceeding 999 of a single type, appropriate numbers are reserved (unassigned) to permit later addition.

Engraving is the best method of placing serial numbers on instruments. Die stamping can easily cause damage. Vibrotooling may cause damage and does not provide for best legibility. Chemical etching carries the risk of unintentionally etching gaging surfaces and causing localized corrosion. In any event, serial numbers are always applied to non-gaging surfaces. For gage blocks and for instruments too small to accommodate a serial number, the number is applied to the instrument's case.

Location of equipment is recorded to provide for easy retrieval of the equipment for calibration or other purposes. Equipment is typically assigned to calibration rooms and tool rooms and then logged in and out of these locations by the users of the equipment.

Calibration Procedures

Calibration procedures ensure consistency of calibration with least laboratory error. (See Error Sources, Module 27-1.)

A calibration procedure is prepared for each type of instrument and standard. Leaving calibration techniques to the judgment of the calibration technician has a high probability of allowing errors due to different techniques among technicians and the likelihood of omitting some features of the instrument from the calibration tests. To guard

against such errors, each calibration procedure should identify:

- applicable standards and measuring instruments
- features of the instrument (or standard) to be tested at calibration
- accuracy limits for each feature
- instruction for testing each feature

Using an outside micrometer as an example, the calibration procedure may specify the standard as a 2.0 accuracy grade gage block set at the measuring instruments as optical flat and electronic height set. The features to be tested include size measurement accuracy, flatness and parallelism of anvil and spindle face, and axial and radial play of the spindle. Accuracy limits may be 0.0001 for size measurements, 0.000010 for flatness and parallelism and 0.0001 for axial play and for radial play. The instructions would delineate measurement of gage blocks selected to represent a value in each quarter-range, use of optical flat and monochromatic light to measure flatness and parallelism, and measurement of axial and radial play with the electronic height gage.

Irrespective of the instrument to be calibrated, each calibration procedure typically includes the elements listed in Table 27-6-2.

Intervals of Calibration

Calibration interval means the time for one calibration to the next calibration of a given instrument or standard. It is sometimes termed calibration frequency.

Calibration intervals are established on the basis of stability, purpose, degree of usage, precision, and accuracy. The exact calibration interval for a given instrument is established to ensure a definite probability of recalibrating the instrument prior to it being out of calibration. For example, a company may establish the policy of establishing

Table 27-6-2

Typical Arrangement of Calibration Procedure

Procedure Section	Purpose of Section
Title Page	Provides identity of the specific procedure by title; typically includes a unique number as well.
Introduction and Description	Identifies the instrument whose calibration is described by the procedure. Lists the instrument characteristics and calibration methods, typically in tabular form. Lists of any instrument accessories which are to be included in the calibration.
Equipment Requirements	Lists instruments, accessories, and standards necessary to perform the calibration. Typically lists minimum performance requirements which serve as the basis for selecting alternative instruments.
Preliminary Operations	Includes applicable instructions or preliminary steps prior to commencing the calibration steps. Examples include instrument connections, warm-up, set-up, and special environmental conditions.
Calibration Process	Provides step-by-step instructions for performing the calibration. Includes methods, interconnections, control settings, verifications, and use of calibration curves or charts. Identifies performance limits for each measurement or test. May include work sheets dependent upon complexity of calibration process. Provides a check list or record for recording each measurement and test.

calibration intervals such that 90% of the instruments will be within accuracy limits at calibration. As actual results deviate from the established goal, calibration intervals are lengthened or shortened as appropriate.

The National Conference of Standards Laboratories describes in their Recommended Practice #1 five general methods in use for the establishment of calibration intervals. These methods are engineering intuition, fixed interval through data, variable intervals, interval by use time, and interval by in-use testing. These methods are summarized below.

- Fixed Interval Through Engineering Intuition - This is by far the most prevalent method in use today. It requires that individuals with experience in the general subject equipment area generate an educated guess as to how long an item might be expected to remain within a specified tolerance. This method of determination usually treats the model and manufacturer as a group. It is seldom treated as a generic classification, e.g., micrometers, height gages. This method usually serves as the starting point for all other methods. It has the following advantages and disadvantages:

  Advantages

  Lowest initial expense.
  Offers short term flexibility.
  Serves small number of items well.

  Disadvantages

  Ultimate expense may be quite high through incorrect decisions.
  Requires the same individuals who made the initial decision or others equally qualified to monitor and adjust periods.

Does not yield useful substantiative data.

Does not establish relability level.

- Fixed Intervals Through Data - Using attribute data from calibration reports, decisions may be made on the magnitude of lengthening or shortening periodic intervals. There are various forms of evaluation using statistical techniques and decision criteria. The data must be meaningful in terms of instrument accuracy through normal use. For example, repaired and damaged item data are eliminated. The data from calibration is compared with guidelines such as those listed in Table 27-6-3 in order to adjust calibration intervals:

Table 27-6-3

Sample Guidelines for Adjustment of Interval Through Data

% of Instrument* Out-Of-Tolerance Incoming to Lab	Present Period Month	Change To Month	Pres. Period Mo.	Change To Month	Pres. Per. Mo.	Change To Month
25% or more	3	1	6	3	12	6
15 to 25%	3	2	6	4	12	9
10 to 15%	3	3	6	6	12	12
5 to 10%	3	4	6	9	12	18
5% or less	3	6	6	12	12	24

*Single type or generic group

The fixed interval through data method of determination usually treats the model and manufacturer as a group. It may also be used by serial number or generic group. It has the following advantages and disadvantages:

Advantages

Establishes definite reliability level.

Yields useful substantiative data.

May be programmed for automatic data processing.

Ultimate expense should be low through supported decisions.
Serves large calibration workloads well.

Disadvantages

Initial expense is high.
Inefficient for small samples.
Chronic failing instrument is overloaded.
Requires sophisticated data acquisition and handling.

- Variable or Floating Intervals - This method treats an individual item or instrument separately in one of several ways. For example, automatic data processing or manual history records based on the established reliability criteria are used to evaluate the individual item each time it is processed and the date of next calibration is assigned. Or, without regard to history records and specific reliability criteria, each time an individual item is processed and found to be within tolerance the technician expands the next interval by a certain amount (e.g., increase by one month). If an out-of-tolerance condition is found, the subsequent period is shortened (e.g., decrease by one month). The variable or floating technique treats individual items by serial number only. It has the following advantages and disadvantages:

  Advantages

  Highly responsive to needed interval adjustments.
  By not using historical records it costs little to operate.

Disadvantages

Overlooks need for immediate technician investigation.

A smooth calibration workload is difficult to achieve.

By not using the history/reliability method a definite reliability level would not be known.

Susceptible to subjectivity of individual technician unless carefully monitored.

- Interval by Use Time - This method requires that an elapsed time indicator or usage tag be installed on the item to be calibrated. After a predetermined "on" time has been reached the instrument is submitted for calibration. This method of determination usually treats the model and manufacturer as a group. It may also be used by serial number or generic group. It has the following advantages and disadvantages:

  Advantages

  Frequently used equipment receives proportionally more attention than rarely used instrumentation.

  Disadvantages

  Usable only if the following conditions are met: Elapsed-time indicator is properly activated. Proof of usage data versus deterioration with time. Free from "off" time drift. Deterioration to be free from number of "on-off" sequences, loading, handling, etc.

  High initial cost.

  Easy for user to tamper with, (disconnect timer or run backwards).

  A smoothly controlled calibration workload is difficult to achieve.

  High cost of monitoring timers and policing program.

- Interval by In-Use Testing - Critical parameters within instruments are checked frequently (daily, weekly or monthly) in their use environment using portable calibration equipment. For this, data is collected and statistically analyzed to determine need for a complete calibration of instrument parameters. This method integrates calibration into a quality control function. The in-use testing technique may treat items individually by serial number or by model-manufacturer. It has the following advantages and disadvantages:

  Advantages

  Provides any attainable reliability level desired.
  Provides useful peripheral data, both attribute and variable.
  Provides maximum availability for user.

  Disadvantages

  Not practical for geographically separated instruments.
  Requires sophisticated data acquisition and handling.
  Requires detailed management.
  Requires close inventory control to find instrument to be monitored.
  Present calibration equipment not completely suitable for portable use.

The techniques described by the foregoing are in the simplest form. With certain modifications many of the disadvantages listed might be overcome. Also, there is considerable cross-over in these techniques and portions of each may be used in constructing a satisfactory program. In any event, it should be remembered that there are five

sources which may independently cause an out-of-tolerance condition:

- Improper calibration procedure.
- Improper standards or calibration equipment.
- Improperly or marginally designated instruments (items under test).
- Technician error.
- Improper calibration interval.

Therefore, the calibration interval should not be adjusted on the strength of out-of-tolerance data alone; rather, engineering investigations of all possible causes should be accomplished to assure that a change to the interval is, in fact, the proper action.

Recall Procedure

The recall procedure ensures accomplishment of calibration within the calibration interval. It is normally established through an accountability system. For companies having few instruments, the calibration laboratory technician normally possesses and is accountable for all instruments. The technician requires log out and log in of the instruments by inspectors. In this manner, the technician knows the whereabouts of each instrument and can recall them for calibration at the established intervals.

For companies having many instruments, a similar procedure is established with satellite tool rooms. The main calibration laboratory assigns instruments to various tool rooms throughout the facility. Each tool room technician in turn maintains an accountability system, such as a log in/log out system, such that an individual is accountable for any given instrument at any time.

Each tool room technician has a "tickler" system which flags instruments to be recalled each week (or each month). Such tickler systems may be master listings of calibration

intervals, arrangement of instrument calibration records by due dates, wall charts, computer print-out, or other method.

Traceability

The calibration program must demonstrate a valid relationship of each calibration with the national standards or an accepted value of natural physical constants. As indicated previously in Figure 27-6-1, calibrated reference standards are used in the calibration of an instrument. Each standard is in turn calibrated until either the national standards or recognized natural physical constant is reached in the hierarchy of standards.

Calibration records provide for the documentation of traceability. The calibration record for each measuring device or standard contains sufficient entries to identify the accuracy of the device or standard and the calibration standard or physical constant used in the calibration process. These record entries include:

- reference standards (or physical constants) used to perform the calibration.
- calibration date.
- calibration facility.
- environmental conditions.
- accuracy data.

Traceability is not required for natural physical constants nor for a standard derived from traceable standards by use of physical laws.

Precalibration Checks

In addition to specific calibration procedures for each type of instrument or standard, a procedure is necessary to ensure that accuracy is checked prior to commencing the calibration process. Such a procedure requires testing the accuracy of the instrument prior to any adjustment or repair.

This permits discovery of those cases where an out-of-calibration instrument may have been used for product acceptance or in calibration processes. Also, it develops data which may be used as a basis for adjusting intervals of calibration.

Labeling

The user of an instrument or standard should be able to readily determine if calibration has occurred within the established interval. Evidence of such calibration status can be afforded by color coding, tagging or labeling.

Color coding schemes assign colors to each month and a dot of color representing the month the instrument is next due for calibration is painted on the instrument or its case.

Tagging schemes attach tags to the instrument or its case. The tags may represent the color coding scheme or may contain data entries which identify data of last calibration and due date for the next calibration.

Labels having adhesive backing are applied to the instrument or its case. The label has data entries which identify date of last calibration, name of individual who performed the last calibration, and the due date of the next calibration. Labeling is typically required provided the label does not interfere with the function of the instrument. Few instruments are so small as not to accept the label and labels are available which remain adherent and legible in the oily environment of the machine shops. The label is normally placed in a prominent position on the instrument and it is easily read.

Nonconformance

The calibration program must establish responsibilities and practices for identifying and acting on nonconformances. Such nonconformances fall into one of three general groupings:

- measuring devices or reference standards found to be out-of-calibration.
- measuring devices or reference standards found to have been improperly maintained or improperly calibrated.
- measuring devices or reference standards found to have evidence of damage.

Whenever a nonconformance is identified, the instrument or standard is promptly removed from service and an evaluation is made on the effect of such nonconformance. The evaluation determines if there is probability of product or calibrations having been incorrectly accepted because of the nonconformance. To accomplish this, the evaluation includes:

- determination of the inaccuracy of the instrument or standard.
- identification of all equipment inspected or calibrated by the nonconforming instrument or standard since the date of the last calibration of the nonconforming item. (Note: if it is known that the nonconformance was caused by damage on a known date, only the effect on equipment since occurrence of the damage is identified).
- investigation of the effect of using the nonconforming item.

The investigation of the effect of using the nonconforming item is documented and serves as the basis for accepting or retesting affected equipment. The investigation compares the known inaccuracy of the nonconforming item with its prior

uses to determine if it may have caused incorrect acceptance of product or calibrations. Where such comparison is not possible, results of retesting a sample of the affected equipment may serve as a basis for concluding the exact effect. Product or calibration believed to be adversely affected by use of the nonconforming item is retested.

Environmental Controls

The calibration program includes appropriate environmental controls to prevent environmental conditions from adversely affecting the accuracy of measuring devices and reference standards. These controls apply to the transport, storage and calibration of instruments and standards. Where environmental conditions cannot be controlled as desired, appropriate correction factors are determined and used to ensure accuracy.

The exact environmental controls are dependent on the types of instruments and standards and their susceptability to functional deterioration. Table 27-6-4 lists the environmental factors which are considered and the general effect of these factors.

With respect to temperature controls, a unique condition exists within calibration rooms. Items to be calibrated which are brought in from other areas are not necessarily at the same temperature as the calibration room. These items must "soak" for a time period to permit their temperature to equalize with the temperature of the reference standard.

Records

The records which support the above elements of the calibration program are generally the master serialization listing, instrument assignment log, calibration record card, delinquent report, calibration status labels, and certifications from calibration laboratories or U.S. National Bureau of Standards.

Table 27-6-4

Environmental Factors

Factors	General Adverse Effect
Temperature	Thermal expansion and contraction, alter operation of electronic items and heat sensitive parts.
Humidity	Corrosion from excess humidity, static electricity interference from insufficient humidity, alter operation of humidity sensitive parts.
Vibration	Accuracy of measurements, stability of items containing movable parts, stability of items sensitive to shock.
Radio Frequency Interference	Alters operation of electronic equipment.
Electro-Magnetic Interference	Alters operation of electrical and electronic equipment.
Background Radiation	Alters operation of radiation detection and measurement equipment.
Dust	Contact measurement interference, static electricity, stability of movable parts.
Cleanness	Contact measurement interference, soundness of electrical connections, staging errors.
Fumes	Corrosion, alter operation of equipment.

- Master Serialization Listing - This listing provides a running inventory of instruments and standards and their assigned serial numbers. Where thousands of instruments are on hand, the company may use a computer for storing, updating, and printing the listing. The supervisor of the calibration laboratory or the chief inspector is normally responsible for maintaining the listing. Purchases of additional instruments and standards must involve the responsible person to permit updating the listing and assignment of serial numbers.
- Instrument Assignment Log - This record identifies which instruments have been assigned to whom. It serves as an accountability record. It can be a log book or special record format.
- Calibration Record Card - A calibration record card is maintained for each instrument and standard calibrated by the company's calibration laboratory. Results of initial accuracy testing is recorded on this card at each calibration. Such data gives trend information which can serve as the basis for adjusting the calibration interval. For example, if an instrument is found to be accurate without adjustment or repair for three of four consecutive quarterly calibrations, the calibration interval could be changed to semi-annually. This card is illustrated in Figure 27-6-3.
- Delinquent Report - Most companies use some means of notifying responsible persons of instruments which are past due for calibration. Such instruments should have been returned for calibration but for some reason they have not been. The notification can be any format. It can be a listing of delinquent gages sent

CALIBRATION RECORD CARD

Instrument Name: Outside Micrometer, Without Vernier

Size or Range: 2-3" Serial Number: 265003216

Date of Issue: 2-1-78 Tool Room: 6B

Accuracy Limit: ±.0005

Date Of Calibration	Error For Each Quarter Range				Tested By	Adjustments and Repairs
2-1-78	0.0000	0.0000	0.0000	0.0001	JD	None
3-1-78	0.0000	0.0000	0.0000	0.0001	JD	None
4-1-78	0.0001	0.0001	0.0001	0.0001	JD	None
5-1-78	0.0001	0.0001	0.0001	0.0001	JD	None (Int. to 3 mos.)
8-1-78	0.0001	0.0002	0.0002	0.0002	JD	Reset to 0.0000
11-1-78	0.0001	0.0001	0.0001	0.0001	JD	None
2-1-79	0.0003	0.0003	0.0003	0.0003	JD	Reset to 0.0000

Use Reverse as Necessary Form CAL-2

Figure 27-6-3 Typical Calibration Record Card

to responsible supervisors or it can be a special form. Figure 27-6-4 illustrated a typical special form. A duplicate of each issued form is retained by the calibration technician.

- Calibration Status Label - Adhesive backed labels are widely used as the indication of calibration status. Each time the instrument is calibrated, the calibration technician removes the previous label and applies a new label. Such labels are available in a variety of sizes and materials. Labels are made from paper, cloth or aluminum. When paper or cloth labels are used in an oily environment, the calibration technician applies a thin coat of lacquer over the label to preserve the written data. Aluminum

TOOL AND GAGE DELINQUENT REPORT

Date _____ Number _____

TO: _____ Department: _____
Supervisor

FROM: Tool and Gage Calibration Laboratory

The following employees have failed to return the instruments specified below:

EMPLOYEE	Dept.	Instrument	Serial	Due Date

The above must be returned immediately to the Tool and Gage Calibration Laboratory.

_____
Tool and Gage Calibration Foreman

Figure 27-6-4 Delinquent Report

labels can be read by the impression left by a ball point pen. Figure 27-6-5 illustrates a typical "calibrated" label.

Labels or tags are also used to identify rejected items pending repair or replacement. These labels or tags typically state "Rejected - DO NOT USE" and contain entries for the date of rejection, by whom, and cause of rejection.

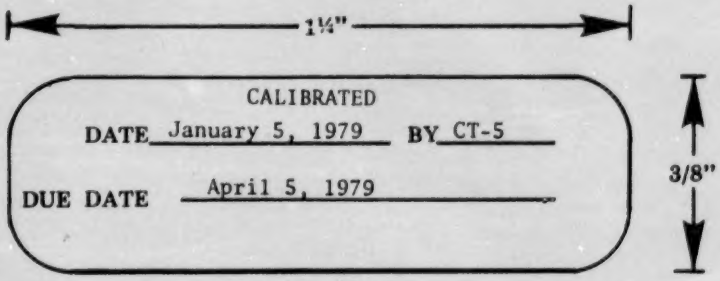

Figure 27-6-5 Typical Status Label

- Certification from Calibration Laboratories - Instruments and standards which cannot be calibrated by the company are sent to commercial calibration laboratories. The commercial calibration laboratory provides a certification of calibration results and provides evidence of traceability of the instruments and standards used by the calibration laboratory. Module 27-3 illustrates a typical certification for gage blocks.

EXERCISES

Laboratory exercises and/or field trips to calibration laboratories are recommended. Laboratory exercises should involve the calibration of selected measuring instruments which have been used during instruction of earlier modules of this course. Guidelines for example exercises and for a field trip are given below.

Exercise #1, Preparation of Calibration Procedure

1. Preparation by Instructor:
   a. Establish working groups consisting of two to four students/trainees each.
   b. Assign to one half of the groups the task of preparing a calibration procedure for a specific instrument. (Note the Procedure section of this module cites a specific calibration procedure for a micrometer caliper. This may be used as an example.
   c. Assign to the other half of the groups the task of preparing a calibration procedure for the standard which will be employed by the first half.
   d. Earlier modules of this course should be available for review as necessary.
2. Task for Students/Trainees:
   a. Each group prepare a procedure for calibrating the assigned instrument or standard. Include the following:
      - standard and/or measuring instrument to be used
      - features to be tested
      - accuracy limits for each feature
      - instructions for testing each feature

b. Upon completion of the calibration procedures, obtain a review of the procedure by a group in the other half. Each reviewing group should determine the workability of the procedure. In addition, each review should state whether the accuracy of the standard would be adequately determined to permit its use in calibrating the instrument.

c. Select one of the procedures which appears to be best and demonstrate its use by calibrating the instrument covered by the procedure. (NOTE: additional procedures may be demonstrated as time permits). Make not if omitted, vague, and incomplete steps of the procedure are revealed by the performance of the calibration. Explain why the initial review failed to detect such weaknesses of the procedure.

Exercise #2, Evaluation of Traceability

1. Preparation by Instructor:
   a. Determine if this exercise may be accomplished locally. If the local program includes serialization and documented calibration of instrument and reference standards, the exercise can be performed locally.
   b. If this exercise cannot be performed locally, arrange for either a visit to a calibration laboratory or for review of a company's procedures. The visit or review should accomplish the tasks of step 2.
2. Tasks for Students/Trainees:
   a. Prepare a check list of items which you consider should be checked to determine if a given instrument has traceability.

b. Determine from the instructor if the evaluation is to be made of local gages, gages at a calibration laboratory or a set of procedures which describes a company's calibration program.

c. Conduct an evaluation for traceability of one gage using the check list as a guide. If procedures are being evaluated, determine if compliance with the procedure results in traceability. If gages are being evaluated, determine what evidence of traceability exists. Ensure the evaluation encompasses:
   - identification of gage
   - calibration of gage
   - identification of reference standards
   - calibration of reference standards
   - certification of accuracy to national standard or accepted physical constant

d. Prepare a report of findings. Include in the report the specific evidence of traceability. Identify any necessary evidence which is found to be nonexistant and recommend what should be done to establish necessary evidence. State your conclusion on whether traceability exists for the gage evaluated.

Exercise #3, Evaluation of Calibration Program

1. Preparation by Instructor:
   a. This exercise is structured for the students/trainees to audit the calibration program which is applied to the measuring devices used in this course.
   b. In the event a formal calibration program has not been established, this exercise could be modified to have the students/trainees assist in the development of a local calibration program.

2. Tasks for Students/Trainees:

a. Prepare a check list of items which you consider are essential features of a calibration program. This check list will be your guide in auditing the local calibration program and it should address the ten elements described by this module.

b. Audit the calibration program using your check list as a guide. The following sequence is suggested:
   - adequacy of procedures
   - adequacy of storage
   - adequacy of environmental controls
   - instrument identification and calibration status
   - traceability
   - compliance with calibration intervals
   - adequacy of recall practices
   - adequacy of pre-calibration checks
   - records
   - control of nonconformances

c. Prepare a report describing the results of your evaluation. For each area where you conclude improvements are needed, state a recommendation for making the improvement and describe the basis for your recommendation. The following format is suggested:
   - Title
   - Scope
   - Personnel Contacted
   - Summary of Results
   - Specific Findings and Recommendations

Exercise #4, Verification of a Specific Calibration

1. Preparation by Instructor:
   a. This exercise provides for students/trainees to verify the adequacy of a specific calibration.
   b. To perform this exercise, students/trainees will require access to a specific instrument which has been previously calibrated, the calibration procedure, and all equipment required by the calibration procedure to perform the calibration.
2. Tasks for Students/Trainees:
   a. Obtain from the instructor the specific instruments whose calibration will be verified.
   b. Study the calibration procedure applicable to the given instrument. Determine if the procedure appears to be adequate. Consider the following and note any comment you have have:
      - clarity
      - suitability of reference standards and measuring and test equipment
      - adequacy of listing of features to be tested
      - completeness and logic of calibration steps
      - adequacy of acceptance criteria
   c. Calibrate the given instrument by explicitly following the calibration procedure. Do not use your notes on the adequacy of the procedure. As you perform the calibration, make separate notes on any difficulties encountered in performing the calibration.
   d. Compare results of your calibration with the calibration record card for the given instrument. If your results differ, repeat the calibration as necessary until you are confident of the validity of your results.

e. Determine if the calibration procedure provides for adequate calibration. This determination should be based on comparison of your two sets of notes and the results of your calibration with the calibration record for the instrument.
f. Report improvement needed in the calibration procedure and the basis thereof.

MATERIALS

Materials for exercises suggested by this module are to be selected from the material recommended by Modules 27-2, 27-3 and 27-4. If the specific procedure for calibration of a one-inch micrometer caliper is employed, the materials requirements will be as follows:

1. A one-inch micrometer caliper.
2. Gage blocks of the following size ranges:
   a. Less than 250 mils in height.
   b. In the range between 250 mils and 500 mils in height.
   c. In the range between 500 mils and 750 mils in height.
   d. In the range between 750 mils and 1000 mils in height.

CALIBRATION PROCEDURE FOR OUTSIDE MICROMETER

Introduction and Description

This procedure is to be used for an outside micrometer. It is specifically outlined for a one-inch micrometer, however, it may be used for any outside micrometer using these same basic principles.

Check the particular micrometer size and range which needs to be calibrated. The outside micrometer caliper is defined in terms of the maximum measurement obtained by the instrument.

Equipment Requirements

A set of gage blocks will be necessary for the micrometer calibration procedure. These are used for checking the instrument over each quarter of its total measurement span. For example, a one-inch micrometer may be calibrated using four gage blocks of the following sizes:

1. Less than 250 mils.
2. In the range between 250 and 500 mils.
3. In the range between 500 and 750 mils.
4. In the range between 750 and 1000 mils.

Preliminary Operations

Perform a visual inspection of the micrometer ensuring:

1. Cleanliness of the measuring faces.
2. Proper operation of the barrel and thimble.
3. Proper operation of the friction or adjusting nut used to compensate for wear between the screw portion of the spindle and the nut.
4. For micrometers furnished with a spindle lock or clamp ring, the use of this device shall not alter the distance between measuring faces by more than 0.0001 inch.

5. Micrometers are usually designed for operation at approximately 68°F. Verify this for the micrometer in question and ensure that room temperature is 68° ± 2°F.

Calibration Process

1. Set the micrometer faces to the "closed" position and "zero" check the micrometer. Repeat this operation 5 times taking the average of all five readings.
2. Open the micrometer faces and insert the gage block that is less than 250 mils in level and measure this calibrated block 5 separate times, taking the average of all five readings.
3. Repeat step 2 for each of the three remaining gage blocks taking five separate measurements for each block and once again averaging the readings.
4. From the average of each of these five measured readings at each of the five measured locations, determine if the micrometer is accurate to within ± 0.0005 in. of the gage block reading. (Note; the accuracy of a specific micrometer may be greater than ±0.0005 in. In these cases, the micrometer should be calibrated taking the actual designated accuracy into account).

DATA TABLE

None.

REFERENCE MATERIALS

IEEE Std 498, Requirements for the Calibration and Control of Measuring and Test Equipment Used in the Construction and Maintenance of Nuclear Power Generating Stations, The Institute of Electrical and Electronic Engineers, 345 East 47th Street, New York, New York 10017

Busch, Ted, Fundamentals of Dimensional Metrology, Delmar Publishers, Third Edition, 1966.

Covino, Charles P. and Meghri, Angelo W., Quality Assurance Manual, The Industrial Press, First Edition, New York, New York, 1962.

Farago, Francis T., PhD., Handbook of Dimensional Measurement, Industrial Press Incorporated, Third Printing, 1968.

Juran, J.M., Quality Control Handbook, McGraw-Hill Book Company, New York, New York, Third Edition, 1974.

Society of Manufacturing Engineers, (SME), Handbook of Industrial Metrology, Prentice-Hall, Incorporated, 1967.

National Conference of Standards Laboratories

Recommended Practice #1, Establishment and Adjustment of Calibration Intervals

Recommended Practice #3, Preparation of Calibration Procedures

Recommended Practice #4, Calibration System Specifications

TEST

Read each question carefully. Be sure to provide the specific information each question requires. Make your answers brief. Use the backs of the test if you need more space.

1. Define the following terms:

   a. calibration_____

   b. traceability_____

   c. national standard_____

   d. reference standard_____

   e. out-of-calibration_____

2. Describe the role of the U.S. National Bureau of Standards with respect to calibration.

3. State the principle associated with traceability and describe its role in the calibration program.

a. principle_____

_____

_____

_____

b. role_____

_____

_____

_____

4. Name four sources which may independently cause an instrument to be out-of-calibration.

a._____

_____

b._____

_____

c._____

_____

d._____

_____

5. Briefly describe the contribution to calibration program by each of the following elements of a calibration program:

a. calibration procedures_____

_____

_____

_____

b. intervals of calibration_____

_____

_____

_____

c. recall procedure _____

_____

_____

_____

d. precalibration checks _____

_____

_____

_____

e. labeling _____

_____

_____

_____

Multiple Choice. For question 6 through 11, circle the letter of the choice which best answers the question or satisfies the statement.

6. The most prevalent method of adjusting calibration intervals is by "educated guess" by experienced persons. This method is called:
   a. fixed interval through data
   b. fixed interval through engineering judgement
   c. variable interval
   d. use time interval

7. What is the name of the method of adjusting intervals of calibration wherein each individual instrument's calibration interval is adjusted at each calibration?
   a. fixed interval through data
   b. interval by use time
   c. interval by in use testing
   d. variable or floating interval

8. The method of adjusting intervals of calibration by fixed interval through data method relies upon:
   a. judgement of experienced persons
   b. statistical analysis of calibration results for each grouping of instruments
   c. collection of "on" time as indicated by usage tags
   d. frequent checks of critical parameters during normal use of the instrument.

9. The limits of accuracy to be met by instruments at calibration is specified by each company based upon:
   a. national standards
   b. calibration history data of instruments
   c. capability and expected use of instruments
   d. known intervals of calibration.

10. Whenever an instrument is found to have evidence of damage, it is identified as:
   a. calibrated
   b. calibration not required
   c. removed from inventory
   d. nonconforming.

11. A definite relationship between the accuracy of an instrument and the national standard is provided by:
   a. labeling
   b. recall procedures
   c. tolerance-to-accuracy principle
   d. traceability.

Matching. Match the record with its primary purpose by placing the proper letter from the right hand column adjacent the purpose in the left hand column:

Purpose		Record
____ 12.	provides historical evidence of calibration results	a. master serialization listing
____ 13.	serves as an accountability record for individual instruments	b. instrument assignment log
____ 14.	provides an inventory of instruments.	c. calibration record card
		d. delinquent report
		e. status label

Match the environmental condition with its adverse effect on calibration by placing the proper letter from the right hand column adjacent the adverse effect in the left hand column:

Adverse effect		Environmental condition
____ 15.	interferes with wringing of gage blocks	a. temperature
____ 16.	too little causes static electricity	b. humidity
____ 17.	may affect operation of electronic comparator amplifiers	c. vibration
____ 18.	affects accuracy of measurement with test indicator used with height stand and long fixturing	d. electromagnetic interference
		e. dust
		f. fumes

Read the following descriptions of calibration events and state the single most important omission by the calibration technician.

19. A sixteen inch outside micrometer is taken to the laboratory for calibration. The technician immediately calibrates the micrometer using calibrated length rods

and gage blocks. The micrometer is accurate throughout its range within specified limits, no adjustments are made, a new label is applied, and the calibration record card is completed.

_____

_____

20. A depth micrometer assigned to the calibration laboratory is due for calibration. The technician disassembles the micrometer, cleans the lubricates it and reassembles it. Using surface plate, squares and gage blocks, the technician adjusts the micrometer to be accurate within specified limits. A new label is applied and the calibration record card is completed.